BOOST CONVERTER WITH POWER FACTOR CORRECTION

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ABSTRACT

The boost converter is a type of the switched mode power supply which normally to step up the voltage since the voltage output is large than the input voltage. A simple boost converter consists of at least two switching components such as diode and transistor with combine to an energy storage element which is capacitor. As a DC to DC converter, the input of the converter must be a direct voltage and the output with also in range of direct voltage with higher than the voltage input and the switching component control the operation of the converter with the capacitor as the energy storage and the added component is used for filtering purpose. The objective of this project mainly to feed the load of inverter for 3-phase AC motors which is for 300W application and able to supplied the constant voltage output from an AC input voltage. As the scope of this project, the chapter covered as much as to design a boost converter which has power factor correction to be feed on the 3-phase inverter.

ABSTRAK

Penukar rangsangan adalah jenis peningkat voltan yang menghidupkan bekalan kuasa yang biasanya untuk meningkatkan voltan yang mana voltan keluaran adalah besar daripada voltan input. Penukar rangsangan mudah terdiri daripada sekurang-kurangnya dua komponen bertukar seperti diod dan transistor dengan menggabungkan elemen penyimpanan tenaga seperti kapasitor. Sebagai DC ke DC converter, input penukar mestilah voltan langsung dan output dengan juga dalam julat voltan langsung dengan lebih tinggi daripada voltan input dan penukaran komponen kawalan operasi penukar dengan kapasitor sebagai simpanan tenaga dan komponen yang ditambah digunakan untuk tujuan penapisan.Objektif projek ini terutamanya untuk memberi bekalan kuasa kepada beban penyongsang 3 fasa bagi permohonan kuasa 300W dan boleh dibekalkan voltan keluaran malar daripada voltan input AC. Berdasarkan skop projek ini, bab ini meliputi sebanyak merekabentuk penukar rangsangan yang mempunyai pembetulan faktor kuasa untuk digunakan sebagai bekalan kuasa bagi penyongsang 3-fasa.

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LIST OF ABBREVIATIONS

AC	Alternating Current
PWM	Pulse Width Modulation
PC	Personal Computer
THD	Total Harmonics Distortion
DPF	Displacement Power Factor
PF	Power Factor
PSU	Power Supply Unit
SMPS	Switch Mode Power Supply
CCM	Continuous Conduction Mode
MOSFET	Metal Oxide silicon Field Effect Transistor
OVP	Over voltage Protection
UVP	Under voltage Protection
OPL	Over Power Limitation
EMI	Electromagnetic Interference

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CHAPTER 1

INTRODUCTION

1.1 Project Introduction

A 3-phase AC motor is widely used in many applications such as compressor, pump, conveyer, industrial drives and the added with software interfacing will ensure the ideal advantages of the 3-phase AC motor. In practice, most of these drives are based on ac induction motor because these motors are rugged, reliable, and relatively inexpensive. The proposed technique on this project are based on single phase to three phase conversion that was applications in rural areas and also in industries where three phase equipment or motors are to be operated from the easily available single phase supply [1].

These converters are excellent choice for situations where three phase power supply is not available. This needs a strong, efficient and cost effective with high quality single phase to three phase conversion. The added advantage over the single ac motor is that the three phase motor is more efficient and economical than the single phase motor. Advanced PWM techniques are employed to guarantee high quality output voltage with reduced harmonics and sinusoidal input current irrespective of the load. The boost converter with power factor correction is used to obtain the voltage ouput at constant 390V and typically for 300W for the load drive of continuous conduction mode.

1.2 Objective of the Project

The aim of this project is mainly to feed the load of inverter for 3-phase AC motors for the motor drive by using a single AC source. The main objectives are stated as follow:

a) To design a boost converter with having the power factor controller.
b) To test the designed converter for verification.

1.3 Problem Statement

Nowadays most of the installed AC motor was fixed to a certain level of speed and unstable to the load of the motor that distorted and changed at some level of speed. The changing cost is high when there is need of another replacement due to the speed requirement on the load sides. Besides, the speed of 3 phase AC motor installed is unable to monitor.

1.4 Scope of the Project

There have several scopes on achieving the objective mention and covered as much as the aspect of the project designs on finding the suitable method to be used. The development of PC based on frequency inverter for three phase AC motor is needed to be fed with the DC power supply, which is the used of boost converter alongside the power factor correction availability. At this rate, the main scope of this project is to provide the DC supply from an AC supply on the socket wall. The power factor correction controller is the used to verify the 300W that are used on the output stage with the nearly constant voltage output as well.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, the basis theories of continuous conduction mode of boost converter alongside the architecture of the 3-phase induction motor will be reviewed. The switching scheme, power device and control technique are described.

2.2 Converter

Converter in power electronics field is an electrical device that converts power from of an electrical signal or power source, by converting it from one form to another. Generally, converter can be classified to 4 categories which are a rectifier, inverter, chopper and cycloconverter. Converters are used for applications such as rectification of AC to DC, or an inversion from DC to a controlled frequency of AC to supply variable speed AC motor, interfacing DC power sources to AC distribution systems such as photoelectric devices and also productions of DC from AC power for subway and for controlled DC voltage for speed control of DC motor in various industrial applications and etc [2].

2.3 Continuous Conduction Mode

In continuous conduction mode, the boost power stage assumes to be in the two states per switching cycle. In the on state, Switch is on and Diode is off. In the off state, Switch is off and Diode is on. The figure below has shown the simple boost converter equivalent circuit with voltage as the references.

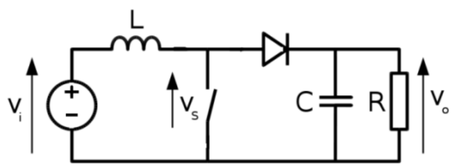

Figure 2.1 Boost converter circuit diagram.

In continuous-conduction-mode (CCM) the current in the energy transfer inductor never goes to zero between switching cycles, as the current continuous and the below figure show the graph of the current.

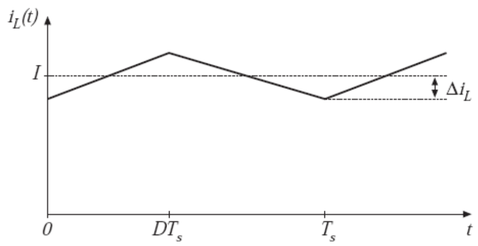

Figure 2.2 Continuous conduction mode inductor current.

At the ON-state, switch S is closed, which makes the input voltage (V_i) appear across the inductor, which cause a change in current (I_L) flowing through the inductor during a time period (t) by the formula:

$$\frac{\Delta IL}{\Delta t} = \frac{V}{L} \tag{2.0}$$

At the end of ON-state condition, the *L* increase as the increases of the inductor is calculated by the formula below:

$$\Delta \mathrm{IL_{On}} = \frac{1}{\mathrm{L}} \int_{0}^{\mathrm{DT}} \mathrm{Vi\, dt} = \frac{\mathrm{DT}}{\mathrm{L}} \mathrm{Vi} \tag{2.1}$$

Where: *D is the duty cycle*

The duty cycle represents the fraction of the commutation period T during which the switch is ON. Therefore D ranges between 0 (S is never on) and 1 (S is always on). Meanwhile, at OFF-state condition, the switch S is open and the inductor current flows through the load. The voltage drop considered zero at the diode, and a capacitor large enough for its voltage to remain constant, the advancement of I_L is given as:

$$\mathrm{Vi} - \mathrm{Vo} = \mathrm{L} \frac{\mathrm{dIL}}{\mathrm{dt}} \tag{2.2}$$

Therefore, the variation of I_L during the OFF-period is:

$$\Delta \mathrm{IL_{Off}} = \int_{\mathrm{DT}}^{\mathrm{T}} \frac{(\mathrm{Vi} - \mathrm{Vo})\mathrm{dt}}{\mathrm{L}} = \frac{(\mathrm{Vi} - \mathrm{Vo})\,(1 - \mathrm{D})\mathrm{T}}{\mathrm{L}} \tag{2.3}$$

The inductor current has to be the same at the start and end of the commutation cycle due to the energy stored in the components. Therefore, the overall change current is zero as the equation below:

$$\Delta \mathrm{IL_{On}} + \Delta \mathrm{IL_{Off}} = 0 \tag{2.4}$$

Substituting ΔIL_{On} and ΔIL_{Off} by their expressions yields:

$$\Delta \mathrm{IL_{On}} + \Delta \mathrm{IL_{Off}} = \frac{\mathrm{Vi\,DT}}{\mathrm{L}} + \frac{(\mathrm{Vi} - \mathrm{Vo})(1 - \mathrm{D})\mathrm{T}}{\mathrm{L}} = 0 \tag{2.5}$$

This can be written as:

$$\frac{\mathrm{Vo}}{\mathrm{Vi}} = \frac{1}{1 - \mathrm{D}} \tag{2.6}$$

This in turn reveals the duty cycle to be:

$$\mathrm{D} = 1 - \frac{\mathrm{Vi}}{\mathrm{Vo}} \tag{2.7}$$

From the above expression it can be seen that the output voltage is always higher than the input voltage (as the duty cycle goes from 0 to 1), and that it increases with D, theoretically to infinity as D approaches 1. This is why this converter is sometimes referred to as a *step-up* converter.

2.4 Power Factor Correction

The power factor of an ac source is determined as the ratio between the real power and apparent power flow to the load in the circuit at the rate from 0 to 1 [6]. Real power is requirement power of the work at the exact time when the work being performed and apparent power is the feedback power given by the components circuit when the circuit operate. At some point, the apparent power may exceed the real power when the energy stored in the load and returned to the source, or due to a non-linear load that distorts the wave shape of the current drawn from the source.

In an electric power system, the power factor problem can occur at in so many causes and the drawn current from the low power factor has increases the real power to be supply which also needs the large size of components. Therefore, the costs may remain the first priority on the charges from the utilities when the low power factor drawn by the consumer that normally the industrial or commercial sector. The domestic consumer is not count on the surcharge but the low power factor problem may affect the equipment been used and also damage some of the other equipment that is sensitive to the distortion and some kind of problem cause by the low power factor.

2.4.1 Power Factor Correction of Linear Loads

The desirable power factor on the load is nearly unity or 1, when real and apparent power is in the same line. The angle between the two powers is 0, but due to the reactive power drawn by the components being use, the unity power factor is not achievable. Therefore, power factor correction may be applied by an electrical power transmission utility to improve the stability and efficiency of the transmission network. Individual electrical customers who are charged by their utility for low power factor may install correction equipment to reduce those costs.

Power factor correction brings the power factor of close to 1 by supplying reactive power of opposite sign by adding the capacitors or inductors that act to cancel the inductive or capacitive effects of the load, respectively. In the electricity industry, inductors are said to *consume* reactive power and capacitors are said to *supply* it, even though the reactive power is actually just moving back and forth on each AC cycle.

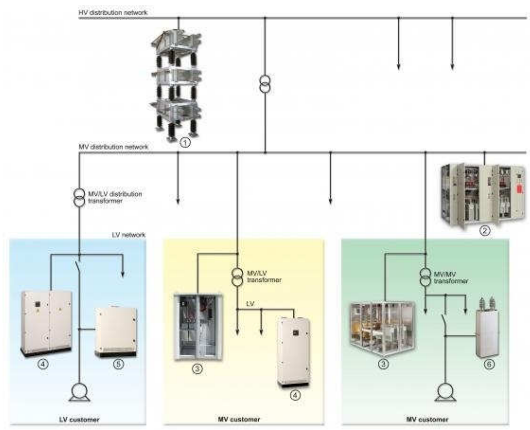

Figure 2.3 Capacitor Bank on the LV transmission Line.

2.4.2 Power Factor Correction in Non-linear Loads.

A non-linear load on a power system is typically a rectifier (such as used in a power supply), or some kind of arc discharge device such as a fluorescent lamp, electric welding machine, or arc furnace [7]. The current in these systems is interrupted by a switching action which containing the frequency components that are multiples with the power system frequency and create the harmonics distortion on the system. The distortion power factor describes how the harmonic distortion of a load current decreases the average power transferred to the load.

$$distortion\ power\ factor = \frac{1}{\sqrt{1 + THDi^2}} = \frac{I_{1,rms}}{I\ rms} \tag{2.8}$$

$THDi$ is the total harmonic distortion of the load current and assumes that the voltage stays undistorted (sinusoidal, without harmonics). This simplification is often a good approximation in practice. $I_{1,rms}$ is the fundamental component of the current and $I\ rms$ is the total current - both are root mean square-values. The result when multiplied with the displacement power factor (DPF) is the overall, true power factor or just power factor (PF):

$$PF = DPF\ \frac{I_{1,rms}}{I\ rms} \tag{2.9}$$

2.4.2.1 Passive Power Factor Correction

The simplest way to control the harmonic current is to use a filter which is possible to design a filter that passes current only at line frequency (e.g. 50 or 60 Hz). This filter reduces the harmonic current, which means that the non-linear device now looks like a linear load but the used of capacitor and inductor however to brings the power factor will need to high current value of inductor and capacitor which is expensive and bulky. The design of passive power factor correction (PFC) is only used the passive components which are inductor and capacitor as the circuit below:

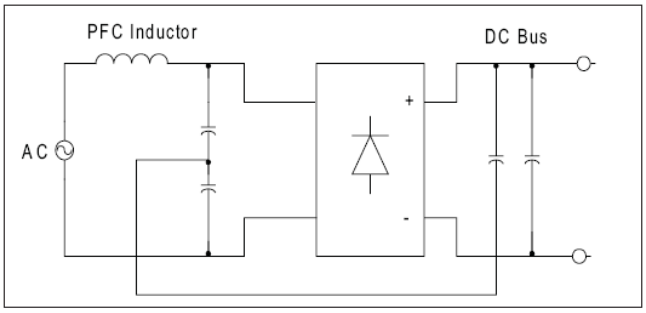

Figure 2.4 A Passive PFC circuit requires only a few components [11].

The passive PFCs are typically more power efficient than active PFCs when used for switching computer PSU with typically around 96% for passive, while an active PFC has efficiency of about 94% [12]. Although pleasantly simple and robust, a passive PFC rarely achieves low Total Harmonic Distortion (THD) and also because of the circuit has operates at the low line power frequency of 50Hz or 60Hz.

2.4.2.2 Active Power Factor Correction

The preferable type of PFC is Active Power Factor Correction and it a power electronic system that changes the wave shape of current drawn by a load to improve the power factor. The purpose is to make the load circuitry that is power factor corrected appear purely resistive (apparent power equal to real power) [9]. In this case, the voltage and current are in phase and the reactive power consumption is zero and that will be benefit to the efficiency of the used power by the consumer.

The active power factor correction manipulates the switched-mode power supply (SMPS), which is the conversion of power in the other form. First the SMPS convert an

AC source to a DC bus, using a bridge rectifier or similar circuit. The output voltage is then derived from this DC bus. The problem with this is that the rectifier is a non-linear device, so the input current is highly non-linear. That means that the input current has energy at harmonics of the frequency of the voltage. Therefore the active PFC is use to compensate with the DC link by control the switching scheme. The common types of active filter are:

1. Boost
2. Buck
3. Buck-Boost

In the case of a switched-mode power supply, a boost converter is inserted between the bridge rectifier and the main input capacitors. The boost converter attempts to maintain a constant DC bus voltage on its output while drawing a current that is always in phase with and at the same frequency as the line voltage. Another switch mode converter inside the power supply produces the desired output voltage from the DC bus. This approach requires additional semiconductor switches and control electronics, but permits cheaper and smaller passive components. It is frequently used in practice. For example, SMPS with passive PFC can achieve power factor of about 0.7–0.75, SMPS with active PFC, up to 0.99 power factor, while a SMPS without any power factor correction has a power factor of only about 0.55–0.65 [10].

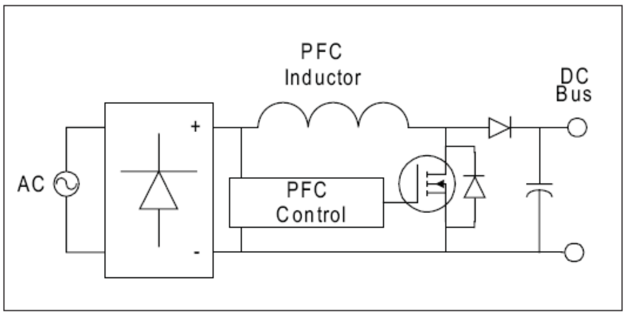

Figure 2.5 An active PFC circuit produces low THD [11].

Active PFC offers better THD and is significantly smaller and lighter than a passive PFC circuit. The reducing size and cost of passive filter elements, an active PFC operates at a higher switching frequency than the 50Hz/60Hz line frequency as the Figure 2.5 shown the active PFC.

2.5 3-Phases Induction Motor

An induction or asynchronous motor is a type of AC motor where power is supplied to the rotor by means of electromagnetic induction. These motors are widely used in industrial drives, particularly polyphone induction motors, because they are robust and have no brushes. Their speed can be controlled with a variable frequency drive [3]. The advantage is that the three phase motor is more efficient and economical than the single phase motor. Also the starting current in three phase motor is less severe than in single phase motor. The following table provides comparisons of the benefits of AC and DC drive technologies.

Table 2.1: Comparisons of the benefits of AC and DC drive technologies [4]

Criteria	DC Drives	AC Drives
Drive complexity	Low	High
Motor complexity	High	Low
Inherent fault protection	No (needs fuses)	Yes
Lifetime maintenance	Required (Motor brushes)	Low (Bearings)
Control performance	Low	High (Closed loop control)

2.5.1 Features of Standard AC Motors

The squirrel cage induction motor is the electrical motor type most widely used in industry. This leading position results mainly from certain excellent features of the squirrel cage motor such as:

a) Uncomplicated, rugged construction. For the user this means low initial cost and high reliability.
b) Good efficiency coupled with low maintenance costs resulting in low overall operating costs.

Squirrel cage motors are asynchronous induction machines whose speed depends upon applied frequency, pole pair number, and load torque. At a constant supply voltage and frequency, if the effect of temperature variations is disregarded, the motor torque will depend upon slip. At a positive slip, the squirrel cage machine will act as a motor - at a negative slip, as a generator. To reverse the machine's direction of rotation, the phase sequence to the motor must be changed. Assuming similar conditions, the phase current drawn by a squirrel cage motor will depend only on the slip. A motor running at synchronous speed will only draw minimum current.

2.5.2 Frequency Controlled Squirrel Cage Motors

In order to use the polyphase AC motor as an adjustable speed device, it is necessary to control and adjust the frequency of the 3 f power applied to its terminals. The operating speed of the AC motor is determined by the following relationship:

$$\text{Shaft Speed (RPM)} = \frac{120 \text{ x Supply Frequency}}{2 \text{ x Pole Pair Number}} - \text{ Slip (RPM)} \tag{2.10}$$

In frequency converter drives, squirrel cage motors are usually run within the range between the peak torques. The single-phase equivalent circuit of the motor, shown in Figure 2, can be used to obtain equations for the torque T, the peak torque T_h and the slip D_{nn} corresponding to the peak torque. The equations are based on the assumption that the magnitude of the phase current I_1, does not affect the voltage U_i.

$$T = 3p\left(\frac{Ui}{\omega 1}\right)2 . \frac{R'2}{\omega 2} . \frac{1}{\left(\frac{R'2}{\omega 2}\right)2 + (L'2\sigma)^2} \tag{2.11}$$

$$Th = 3p\left(\frac{Ui}{\omega 1}\right)2 . \frac{1}{2L'2\sigma} \tag{2.12}$$

$$\Delta n_h = \frac{R'2}{L'2\sigma} . \frac{1}{2 \text{ x } p} \tag{2.13}$$

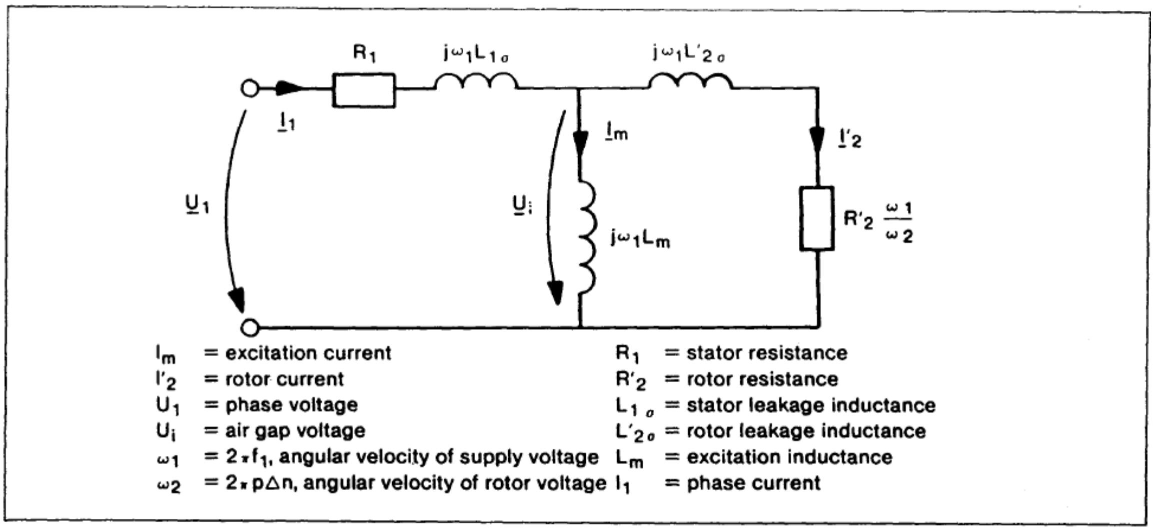

Figure 2.6 Single phase equivalent circuit for squirrel cage motor [5]

CHAPTER 3

METHODOLOGY

3.1 Introduction

The consequences of the method that have been used are described on this chapter, where the technique of the project was discussed. The methodology consists of systematic study of methods that are, can be, or have been applied within a discipline on the project title. On this chapter, the aspect of boost converter with power factor correction (PFC) is discussed as to find the technical on the objective achievement. In General, the methodology can be defined as:

a) Boost PFC characteristic:

1. Power Components Selection.
2. Feedback Arrangement.
3. Input Voltage Sensing.
4. Current Sense Network.

b) Testing procedure:

1. Start up at low line, full load.
2. PF, THD, Efficiency at 110 Vac, full load.
3. PF, THD, Efficiency at 230 Vac, full load.